U.S. Department of Energy's Advanced Industrial Gas Turbines

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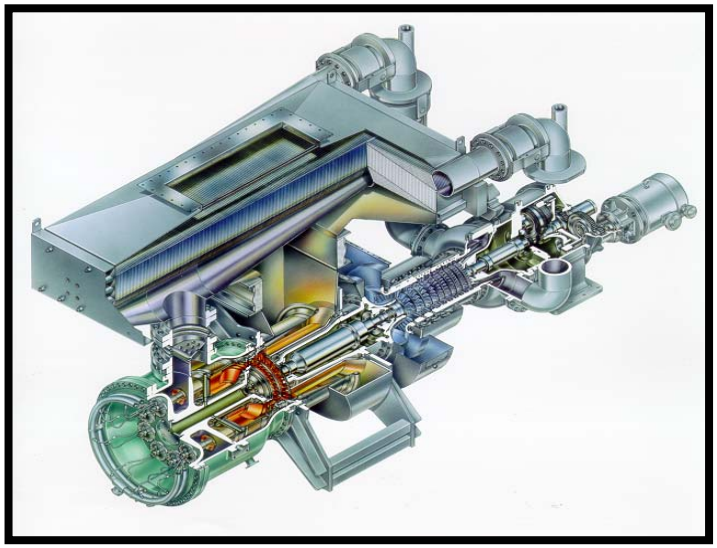
Program Description

The Advanced Turbine Program is focused on lowering emissions and improving the performance of industrial gas turbines. This effort builds on the success of the Advanced Turbine System Program (ATS) that was completed in 2001. Gas turbines in the 1MW to 20MW size will play a critical role in the deployment of Distributed Energy Resources.

Distributed Advanced Turbine Systems

1992

- **28% Efficiency (LHV)**
- **Double digit ppm NOx**



- Advanced designs
- Lower cost operations
- Improved RAMD

2000

- **40% Efficiency (LHV, Simple Cycle)**
- **> 80% Efficiency (CHP)**
- **Single Digit ppm NOx**
- **3.5 cents/kWh (8000hrs/yr)**

Need Exists for Continued Government Investment in Turbines

Significant Message from Industry

- Growing worldwide demand for electricity
- Tightening environmental requirements
- Declining R&D budgets in restructured U.S. electric industry
- Need flexible power generating technology
- Maintain U.S. leadership in multi-billion dollar global power market

Gas Turbine Goals for Low Emissions and Materials

- Development of environmental and performance solutions for gas turbines that broaden opportunities for meeting the nation's energy demand with efficient, affordable, and reliable power.

- To reach this goal, bring together relevant stakeholders in strategic partnerships to develop, test, and commercialize optimized and fully integrated low-emission technologies and advanced materials.

Performance Targets for Industrial Gas Turbines

- Advanced Materials
  - Improved efficiency & environmental performance
  - Elimination of cooling air> 2% gain in efficiency and lower emissions
  - Increase life/durability of new materials > 8000 hrs
  - Higher E/T that expands the market for combined heat and power

- Low Emissions Technologies
  - Target < 5 ppm NOx
  - Consideration for transition to back-up fuels
  - Durable for at least 8000 hours
  - No more than 10% cost add-on
  - No negative impacts on gas turbine performance

Industrial Gas Turbines

2000

Today's ATS

- Low emissions technologies
- Advanced materials development

5 Low Emission Awards

- Precision Combustion Inc
- Catalytica
- Alzeta
- Solar Turbines
- Honeywell

4 Advanced Material Awards

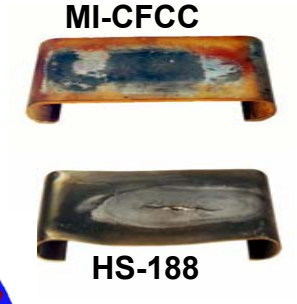
- GE
- Teledyne
- Siemens Westinghouse
- Solar Turbines

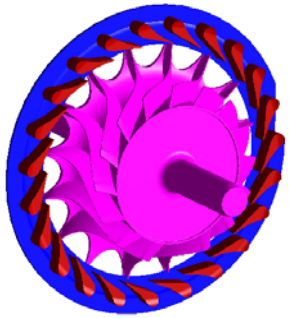
2010

<5 ppm NO_x
Improved performance
< 10% cost add on
>8000 hrs durability

Advanced Materials Solicitation Winners

- GE Corporate Research & Development
- Teledyne Continental Motors
- Siemens Westinghouse
- Solar Turbines



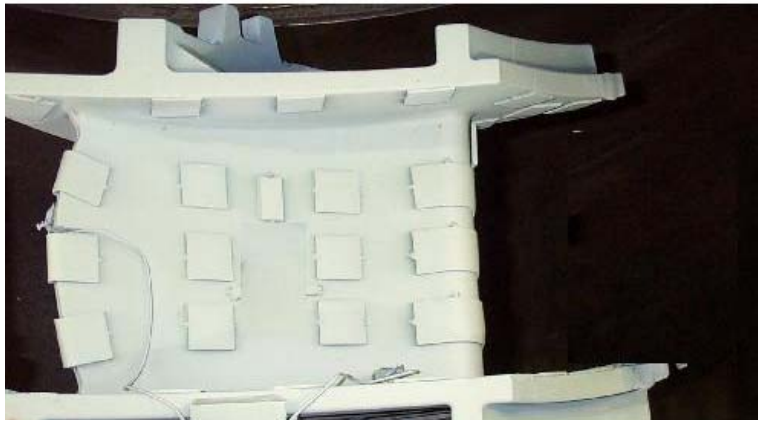


DOE Funding is $7.0 Million over 3 years

Materials Portfolio

- Ceramic Matrix Composites (Continuous Fiber Ceramic Composites) including Environmental Barrier Coatings
  Combustor Liners, Shrouds
- Thermal Barrier Coatings
  Blades, Vanes
- Metal Alloys (powder nickel superalloys and titanium silicon carbide)
  Inlet Nozzle, Rotor, Scroll
- Oxide dispersion-strengthened alloys
  Combustor Liners, Injector Tips
- Monolithic ceramics
  Injector Tips

Seimens-Westinghouse Advanced TBC

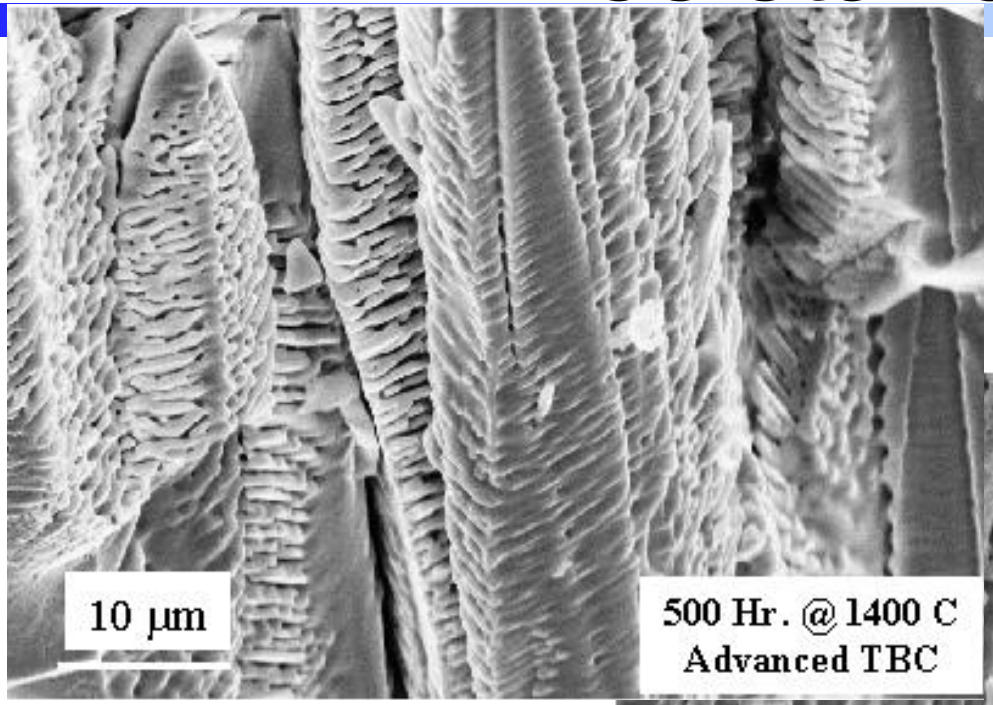


- Columnar microstructure
- Stable composition
- Superior sintering resistance
- EB-PVD & APS
- Meets thickness requirement

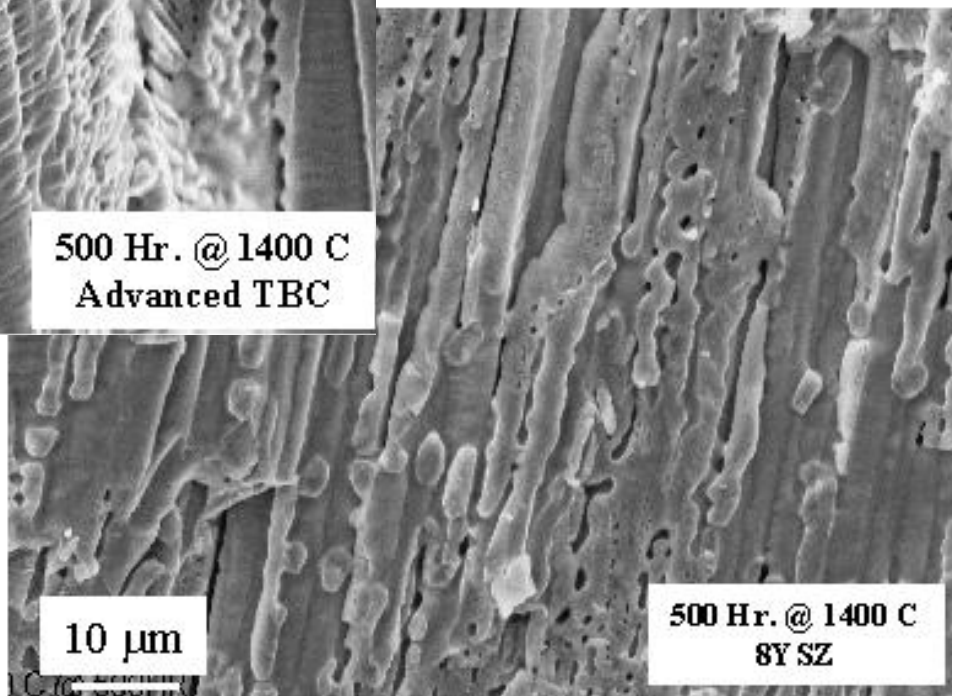
SIEMENS
Westinghouse

Siemens-Westinghouse Improved Sintering Resistance

New



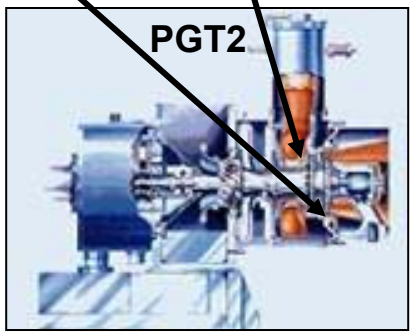
Old

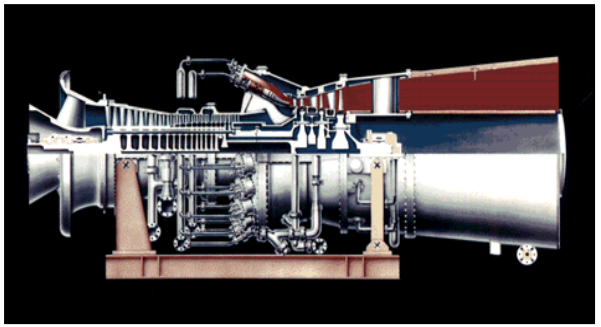


General Electric Ceramic Composites for Gas Turbines

CFCC R&D Program

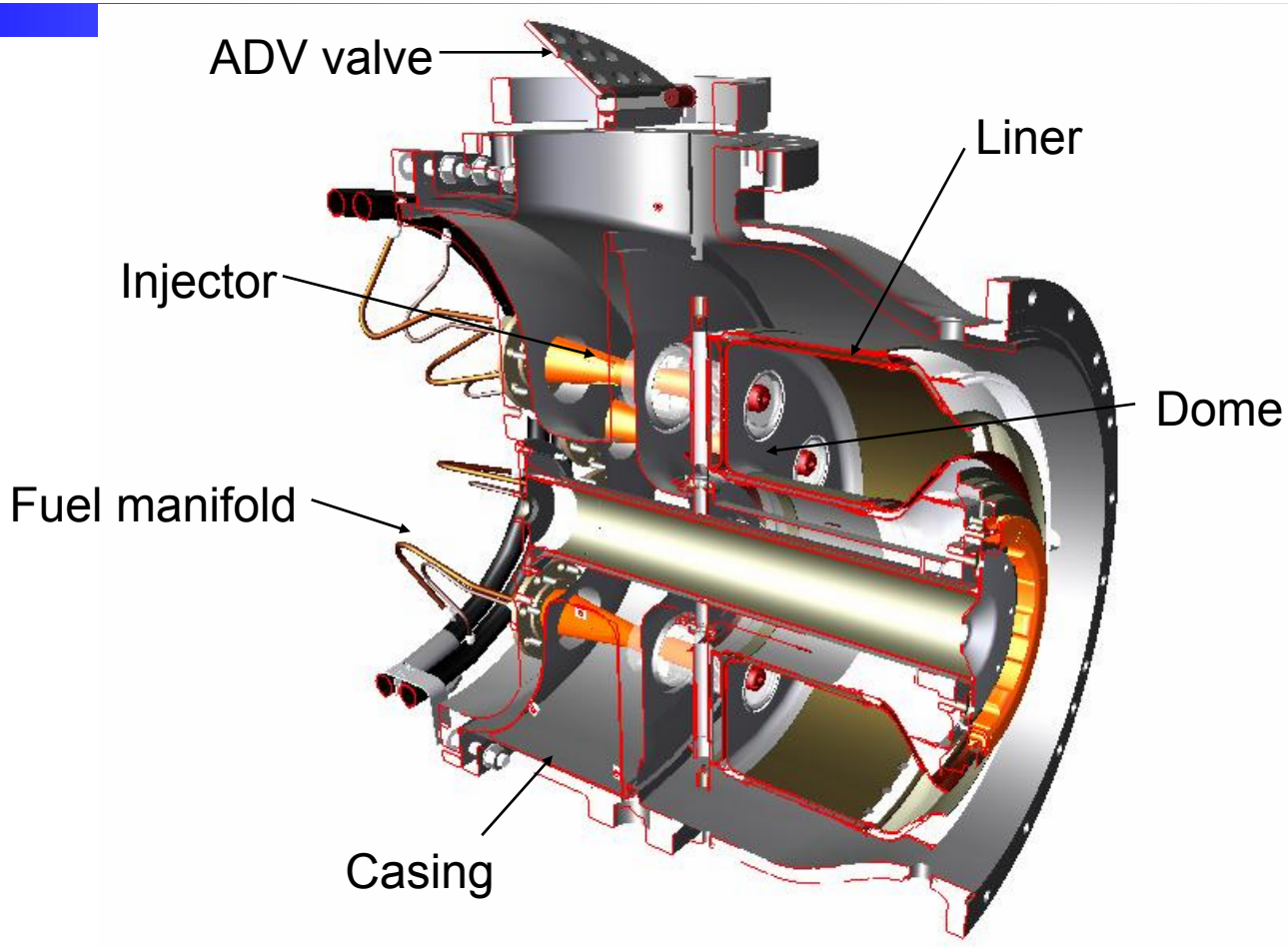
- Higher Temperature
- 1.1 % increase in turbine efficiency
- 3% higher output
- 290 trillion BTU annual savings by 2020





Ceramic Composites in 7F gas turbine

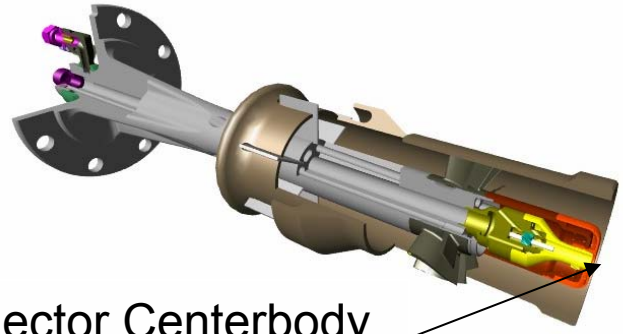
Solar Turbines Mercury 50 Material Challenges of the Combustion Module



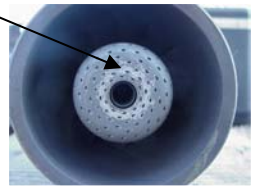
Solar Turbines
A Caterpillar Company

Solar Turbines Mercury 50 Material Solutions

CFCC liners with TBC



Injector Centerbody
Effusion cap



- Combustion liner
  - –CFCC with TBC coatings
    - 14,000 hours single liner
    - 31,000 hours all liners
  - –ODS with enhanced fabricability
- Long-life injector tip
  - –ODS
  - –Monolithic Ceramic
- Coatings
  - –Higher thickness achieved
  - –Increased from 25 mils to 40 mils
  - –Work with U Conn on low TC

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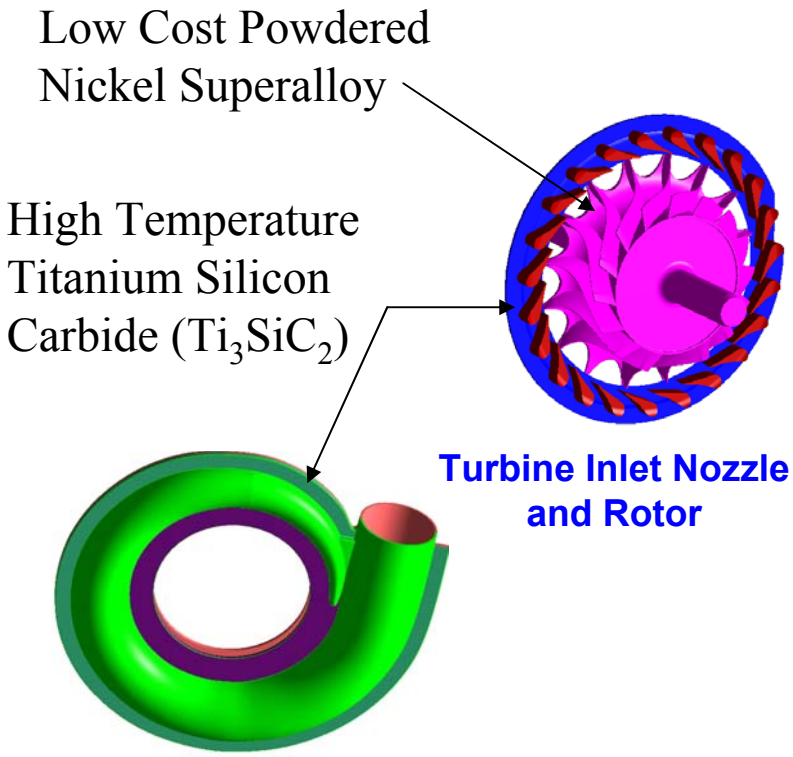
Teledyne Continental Motors Advanced Materials for Turbine Components



- New material systems
  - –Ni superalloy powder casting process
  - –New material Ti_3SiC_2
- Superior high-temp properties
- Improve efficiency 120%
- Reduce manufacturing cost 50%

CONTINENTAL MOTORS
A Teledyne Technologies Company

Gas Turbine Combustor Liners

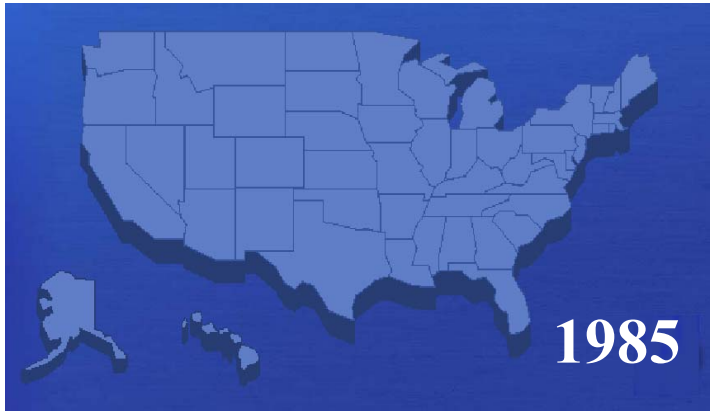
- Liners: H-ACI/BFG SiC/SiC (CVI/MI) w/UTC EBC
- Texaco - Bakersfield, CA
  - >20,780 Hours of Field Operation
  - High Time: >13,937 Hours on One Liner Set
  - Refurbished liners 879 hours
- Malden Mills - Lawrence, MA
  - >16,471 Hours of Field Operation
  - High Time: 9,233 hours
  - Refurbished liners 7,238 hours
- Reduced Emissions
  - <15 ppm NOx, < 10 ppm CO

R&D 100 Award

The 39th Annual R&D 100 Award Winners

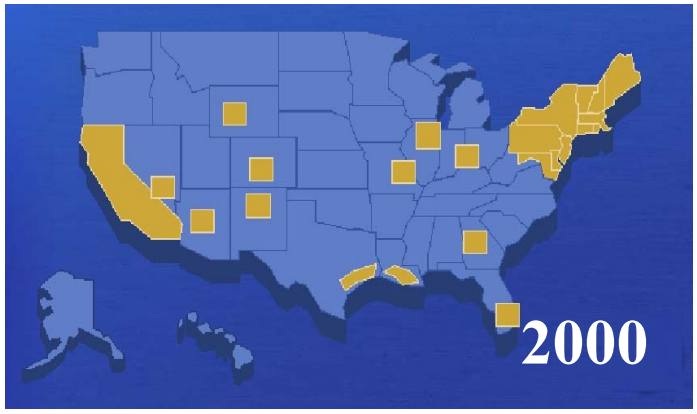
- Two new coatings--Silicon/Mullite/BSAS and Silicon/Mullite+BSAS/BSAS EBCs
- 14,000 hrs of operation at 1250ºC
- NASA Glenn, Research Center, Cleveland, OH; Pratt & Whitney, East Hartford, CT; General Electric Schenectady, NY; Solar Turbines, San Diego, CA

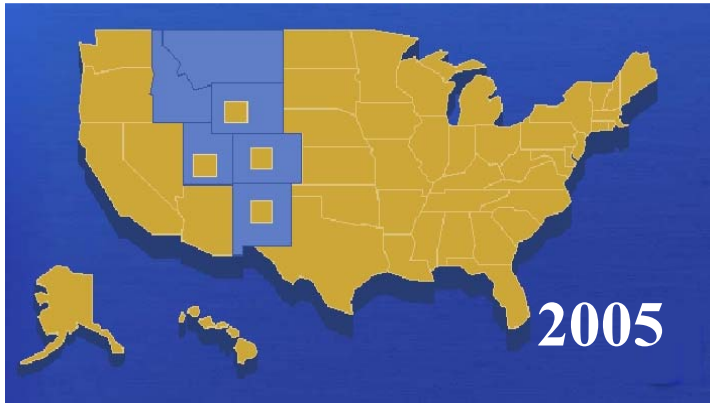
NOx Emissions Limits



> 25 ppm

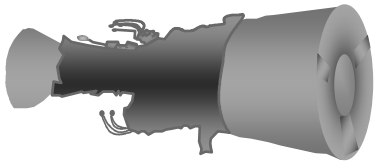
< 5 ppm





Perspective on the Options

Conventional Cleanup



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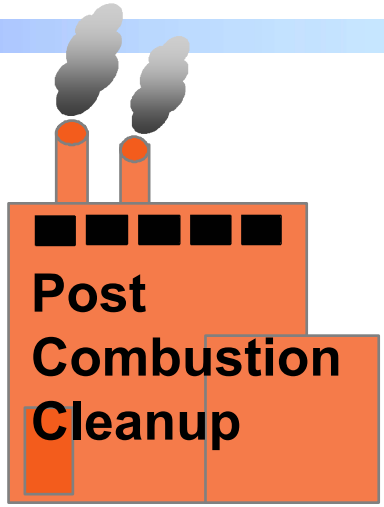
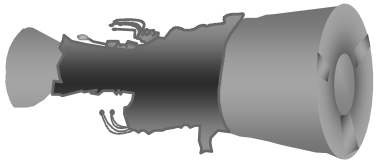
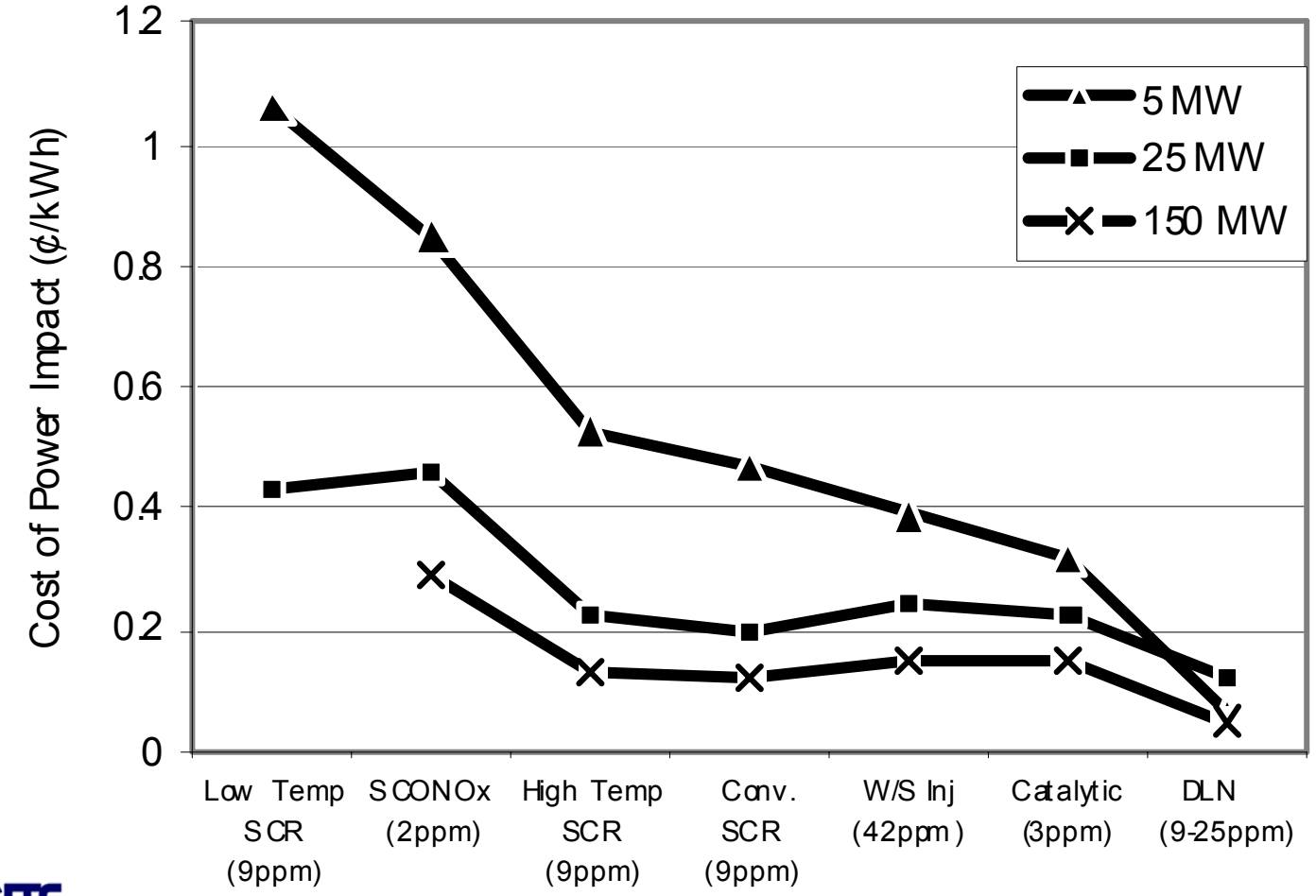


Emission Prevention



Cost of NO_x Control



http://www.eren.doe.gov/der/chp/pdfs/noxreport.pdf

Further Advancement of Industrial Gas Turbines Sought

- Emissions standards more restrictive
- Horizons of new technologies
- New targets
  - < 5 ppm NOx
  - Consideration for transition to back-up fuels
  - Durable for at least 8000 hours
  - No more than 10% cost add-on
  - No negative impacts on gas turbine performance

Low Emission Solicitation Winners

Technology Providers

- Precision Combustion Inc (PCI)
- Catalytica Combustion Systems Inc
- Alzeta

End-Users

- Solar Turbines
- Honeywell Engines

DOE Funding is $6.0 Million over 3 years

Low Emissions Portfolio

- Lean Premix Combustion
- Catalytic Combustion
- Surface Stabilized Combustion

Lean Premix Combustion

- Objective
  - Develop improved lower cost emission prevention methods that expand market opportunities for today's efficient gas turbines
- Goals
  - Originally earmarked for 25 to 42 ppm NOx and acceptable CO, replacing costly high-CO producing water injection
  - Now pushing technical limits to become the option of choice for many locations

Current LPM Status

- Lean premix (LPM) combustion is bringing new turbines to market
  - < 15 ppm NOx becoming the standard
  - Potential for single digit NOx demonstrated
  - Understanding of long term implications are in progress
- New technologies for stable flames seek low single digit NOx at affordable cost

Catalytic Combustion

- Objective
  - Combust fuel in a gas turbine at NOx levels lower than 3 ppm while maintaining efficiency, durability, and affordability
- Goals
  - Create a technology base for potential users
  - Improve system durability and cost
  - Integrate common goals of the turbine OEMs

Catalytic Combustion Status

- Users and technology owners jointly solving common technical issues
- Long term engine tests prove the maturity and readiness of this technology
- System optimization is being explored
- Controls for seamless and bullet-proof responses to cycle variation are becoming available

RAMD Test At Silicon Valley Power

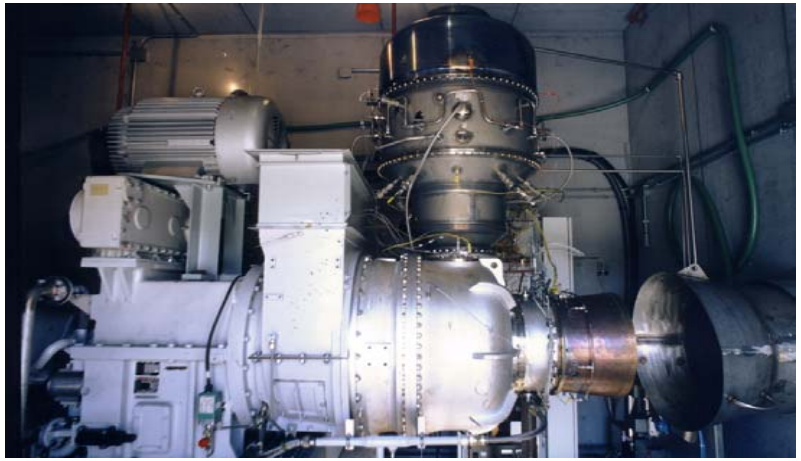
- Reliability, Availability, Maintainability, Durability
- Run 8000 hours on the grid
- Co-funded by:
  - –California Energy Commission
  - –Department of Energy
  - –California Air Resources Board
  - –Gas Research Institute
  - –Electric Power Research Institute

Through 7400 hours:
NOx < 2.5 ppm
CO < 6 ppm
UHC < 6 ppm

Catalytica ENERGY SYSTEMS

Catalytica Combustion System

- Improve performance of Catalyst
- Solve system design problems
- Select optimal materials
- Lower maintenance costs
- Ready for commercial turbine



Alzeta Surface Stabilized Combustion

- Uniform axial flow
- Cast monolithic
- No weld seams
- Selectively perforated
- NOx < 10ppm

T60 Injector

Precision Combustion RCL

- **No preburner**: Compressor discharge
- **Robust**: No flashback / auto-ignition
  Tolerates fuel/air transients
- **Durable**: Well-moderated temperatures
- **Compact**: Available space, low Δp
- **Premixing**: Relaxed requirements
- **Simple**: Air and fuel control
- **Multi-Fuel**: Natural gas, bio-based gas, and pre-vaporized liquids

Full < 3ppm NOx

Pilot < 5ppm NOx

PCI
Precision Combustion, Inc.

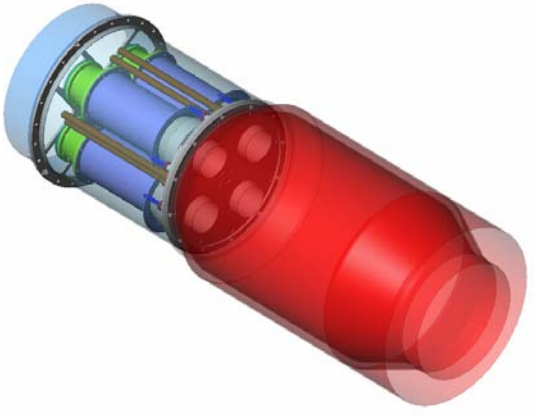
Honeywell ASE50

- Less than 3 ppm NOx
- Fuel flexible
- Good turndown
- Laser emission sensor

Honeywell

Solar Turbines Near-Zero NOx

- Prototype PCI Combustor for T70
- Rig test at T70 conditions <5ppm NOx
- Doable design mods identified & tested
- To test T70 reactor in Saturn Engine



Solar® Turbines
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Opportunities for Catalytic Combustion

Completion of low emission technologies is critical to the Nation's energy security

- Catalytica
  - Three Kawasaki M1A-13X Turbines to be installed for Distributed Generation in the Northeast U.S.
  - Agreement of sale of six GE PGT 10 gas turbines to Alliance Power
- PCI
  - High interest to fill needs of several OEMs

The Malden Mills Experience

New Technology vs Emission Regulations

- Recognition by the regulatory offices that successful R&D merits consideration
- Conditional approval that identifies emerging innovative combustion technology as BACT
- Allots reasonable time (24 months) to shakedown new technology
- Warrants SCR as Fallback

Summary

- Gas turbines will continue to play an important role in the Energy future of the United States by providing clean, reliable, and environmentally-friendly power for the new millennium
- Gas Turbines will be a strong competitive option for distributed power
- Materials technology is a key enabler for advances in gas turbines
- Continued government/industry collaborations will leverage our resources and advance technologies